Standard APIs & Link Prediction for the Digital Thread

Presentation for NIST MBE Summit 2019

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April 2, 2019
Overview

- Challenges in addressing cross-cutting concerns in Engineering
- Engineering of the Future = Digital Thread
- AI for link prediction
Distributed Engineering Information

- One technical system described from different perspectives
- One technical system, but a lot of distributed information
- Distributed information is challenging for collaboration
Overlaps and Relationships in Engineering

- Overlaps due to data duplication (e.g. same parameter used in different models or reports)
- Logical relationships such as a requirement verified by a test case
- The more complex a system is, the more relationships exist between engineering information
Tough Questions for Engineers

[traceability] Is this requirement tested/satisfied? By which architecture/simulation/cad model?

[change management] If we change this requirement, what is the impact for downstream models? How many tests need to be performed again? On the other hand, if a downstream model changes (simulation/cad), what are the upstream impacts on requirements and the system architecture?

[reuse] I have the same requirement in a new project, which elements of the old project can I reuse in the new project (which test cases, which architecture/simulation/cad models)?
According to David Meza, Head of Knowledge Management at NASA

“Most engineers have to look at 13 different sources to find the information they are looking for”

“46% of workers can’t find the information about half the time”

“30% of total R&D funds are spent to redo what we’ve already done once before”

“54% of our decisions are made with inconsistent, or incomplete, or inadequate information”

Quote from https://www.youtube.com/watch?v=QEBVoultYJg
What is the Digital Thread?

Capturing relationships between engineering data across disciplines and across software applications.

Addressing cross-cutting issues efficiently by knowing cross-disciplinary relationships.
2 Trends requiring the Digital Thread

**IoT/Digital Twin**

New feedback loops needed to make sense of recorded operational data

**Complexity of Autonomous Systems**

Explosion of number of test scenarios
Need to link experienced auton. vehicle behavior (e.g. saved in data lakes) with test scenarios (e.g. saved in systems engineering applications) to assess coverage of test scenarios and overall vehicle safety
What does it mean to connect data?

Example:

Requirement identifier <- link type identifier -> Simulation parameter identifier
Connection is between IDENTIFIERS of data

Example: Power budget requirement will have identifier Req-PX-123456
Example: Power parameter in simulation model has identifier Par-PX-7890

Analogy: phone call between 2 persons identified by their phone number
Accessing data identifiers through APIs

Identifiers need to be retrieved from the Application Programming Interface (API) of the data source

Different data sources have different APIs

Example: REST API, Web API, SQL, Java/Python library etc.

Analogy: Different APIs like different power outlets
Digital Thread is currently impossible!

Different APIs everywhere!

- API1
  - Requirements
- API2
  - Test cases
- API3
  - Simulation
Different API = vendor lock-in

Proprietary APIs and Data Formats → Your Data → Your Software Application Vendor
Once Upon a Time Before the Web

- Different protocols to access documents on the internet (Gopher, WAIS, etc...)
- No connected documents (hierarchical document structure, no hyperlinks)
- Not many persons used the internet
- Hypertext existed since 1965, 25 years before the invention of the Web
- Lack of standards for Hypertext hindered adoption of Hypertext - no compatibility between different Hypertext systems
Lessons learned from the Web

- Seeds for innovation: Open standards + open-source
- Web not owned by a software vendor
- Any document can connect to any other document
- Improved knowledge sharing and collaboration
- OSLC driven by similar values than World Wide Web
Principle 1: Standard API

Data is accessible through a standard API

- Versioning of resources
- Discovery of resources
- Constraints on resources
- Change events impacting resources
Principle 2: Unique Global identifiers

Data has unique global identifiers
Principle 3: Connections across silos

Data is connected
Principle 4: Applications decoupled from data

Applications decoupled from data

- True data ownership
- Reusing existing data
Link Manager Goal

Goal
Connect requirements, architecture, simulation and CAD information with links
Link Manager Architecture

Architecture

Link creation in separate neutral application

Link Manager using standard OSLC APIs
Link Viewer
Data Web Application Example

Google-like Search

Private/public Data Web

Distributed Data Silos

Search

Filters
Type:
- Assembly
- ItemPart
- DesignPart
- TraceLink

Origin:
- Supplier1-PLM1
- Supplier2-PLM2
- OEM-PLM1
- OEM-PLM2

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<tr>
<th>RESOURCES</th>
<th>TYPE</th>
<th>ORIGIN</th>
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<tbody>
<tr>
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<td>Assembly</td>
<td>Supplier1-PLM1</td>
</tr>
<tr>
<td>Assembly_2</td>
<td>Assembly</td>
<td>Supplier1-PLM1</td>
</tr>
<tr>
<td>Assembly_3</td>
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<tr>
<td>Assembly_B2</td>
<td>Assembly</td>
<td>OEM-PLM2</td>
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Digital Thread is a Graph

- **RequirementType**
  - Req1
  - Req2
  - Req3

- **TestCaseType**
  - Test1
  - Test2
  - Test3

- **SimModelType**
  - Sim1
  - Sim2
  - Sim3
Graphs have patterns -> Link Prediction

RequirementType

TestCaseType

SimModelType

Req1

Req2

Req3

Test1

Test2

Test3

Sim1

Sim2

Sim3

instanceOf

verifiedBy

instanceOf

using
Link Prediction

- Manual link definition is time-consuming
- Based on patterns in existing links, additional links can be predicted through machine learning, graph mining, and heuristics
Brief History of graph neural nets

“Spatial methods”
- Original GNN
  Gori et al. (2005)
- GG-NN
  Li et al. (ICLR 2016)
- MoNet
  Monti et al. (CVPR 2017)

“Spectral methods”
- GCN
  Kipf & Welling (ICLR 2017)
- Spectral Graph CNN
  Bruna et al. (ICLR 2015)
- ChebNet
  Defferrard et al. (NIPS 2016)

Neural MP
Gilmer et al. (ICML 2017)

“DL on graph explosion”
- Programs as Graphs
  Allamanis et al. (ICLR 2017)
- Relation Nets
  Santoro et al. (NIPS 2017)
- GraphSAGE
  Hamilton et al. (ICLR 2017)
- NRI
  Veličković et al. (ICLR 2018)
- GAT
  Kipf et al. (ICML 2018)

...
3 Investigated Link Prediction Approaches

1. Deep learning
2. Heuristics
3. Graph mining

The digital thread graph is relatively small (compared to social network graphs) and contains complex patterns.

No link prediction approach yet found suitable for digital thread graphs.
Comparison of 3 link prediction approaches

<table>
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<tr>
<th>Approach</th>
<th>Identification of complex patterns</th>
<th>Applicable to small graphs</th>
<th>Computational effort</th>
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<td>Deep learning</td>
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From Model-Based to the Digital Thread

**MBSE**
Focused on specific models, specific data types, specific data structures, specific engineering disciplines

**Digital Thread**
Focused on viewing data as a universal asset, and getting the most value out of ALL the data
Viewing Data as Universal Asset

Electricity played a big role in the Industrial Revolution
Different devices can connect to electric power through a standard power outlet
Data is the new source of power
We need standard APIs to access data, just like we have standard power outlets to access electric power
Thanks and get in touch!

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